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Screening CO_2 capture test for cement plants using a lab scale Calcium Looping pilot facility

Mónica Alonso, Borja Arias, Alberto Méndez, Fernando Fuentes, J.Carlos Abanades*

CSIC-INCAR, Francisco Pintado Fe, 2633011 Oviedo (Spain)

Abstract

This poster presents the first experimental results obtained from a 30 kWth Calcium Looping test facility upgraded to work at conditions closer to those expected in a calcium looping system retrofitted to a cement plant. The main modification in the facility is the use of a second recycle of fine solids (<40 micron) collected in the secondary cylones located after the main calcium loop for CO_2 capture. This allowed the operation of the main calcium loop using finer particle size distributions (dp50 around 60-75 micron), which should generate solid purges more suitable to be processed in clinker ovens. High CO_2 capture efficiencies have been achieved in preliminary experiments with high make-up flow of limestone and high CO_2 concentrations. Further experimental work and modeling activities for an adequate interpretation of results are ongoing within the CEMCAP H2020 project.

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Keywords: CO_2 capture, calcium looping, cement production

1. Introduction

The post-combustion calcium looping process, CaL, has been and continues to be developed at TRL 6-7 for power generation [1-4]. This is a technology that uses CaO as a regenerable sorbent of CO_2 (by interconnecting a high velocity carbonator reactor with an oxy-fired calciner where $CaCO_3$ decomposes into CaO and CO_2). The theoretical synergies of CaL with cement manufacture have been identified in a number of previous simulation works and lab

* Corresponding author. Tel.: +34 985118980
E-mail address: abanades@incar.csic.es

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scale studies [5-14]. However, little information is available on the performance of the main reactors (the carbonator and the calciner) under closer conditions to those expected in a CaL system integrated in a cement plant. The EU CEMCAP project (http://www.sintef.no/projectweb/cemcap/) addresses this challenge by planning a demonstration at TRL 6 of the the CaL technology in cement plants [15]. CSIC is supporting this overall task by screening at TRL4 the impact of the new operating environments on the performance of material and key reactors, using for this purpose a retrofitted lab scale (30 kW_{th}) pilot. This poster communication presents the first results from the test campaigns and discusses on the way forward.

2. Experimental

The scheme of the retrofitted pilot and its general overview is presented in Figure 1. In addition to upgrades for data acquisition and continuous gas analysis, the pilot has incorporated two changes respect to previous configurations [16]:

- New insulation of reactors (right hand side of Figure 1) and additional heating elements to maximize the effective thermal power available for calcination of $CaCO_3$. This is especially important to allow operation at conditions of high make up flow of limestone, as expected in the CEMCAP test.
- A new double recycle loop (left hand side of Figure 1) to allow the 30 kW pilot to operate with finer materials by re-injecting to the primary solid circulation loop fine material (dp50 around 35 micron) collected in secondary cyclones. Fine particle sizes of CaO are known to be required to maximize clinker product quality [17].

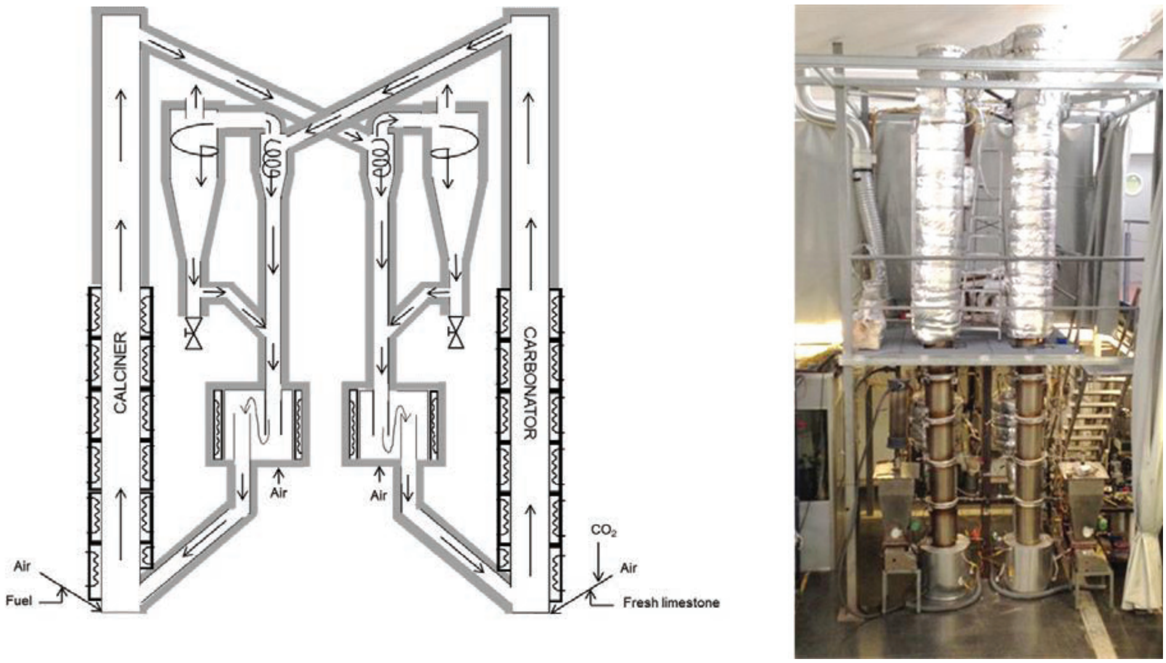

Figure 1. (a) Schematic of the INCAR-CSIC 0.03MW_{th} pilot plant incorporating a 2nd solid loop recycle of fine material (b) General overview of the pilot

Initial commissioning experiments have confirmed excellent closure of solid mass balances (>95%) for solids in the retrofitted test rig. It was also noted a 10-20% of improvement in calcination intensity of $CaCO_3$, moving up to to 3-4 $molCO_2/m^2s$ with superficial gas velocities in the calciner of around 3.5 m/s. However, access to higher capture rates (up to 10 $molCO_2/m^2s$ typical in larger pilots [1] operated in oxy-combustion mode) are beyond the scope of this test rig, and will require testing at higher velocities and/or oxy-combustion calcination conditions in larger scale rigs within the CEMCAP consortium.

Difficulties for steady circulation of fines solids (i.e. around dp_{50}=35 μm) in standpipes where observed during many commissioning test. These could be attributed to typical problems with these devices in small scale rigs (although standpipe diameters of 50 mm and angles>70º where chosen for all connecting solid lines). These difficulties where only partially overcome with increasing number of aeration points and small vibration devices placed on the the standpipes. It should be noted that these CaO rich materials and particles size distributions are routinely handled in commercial cement plants, and therefore, the circulation problems detected in our pilot are rig-specific and not process-related. These problems limited the duration of steady states of typical experiments. Figure 2 shows a typical experiment with CO_2 capture from a gas with a content of 18%v of CO_2. The figure in the left hand summarises the conditions, referring to solid inventory and solid circulation rate in the main solid circulation loop. The operation with these fine solids translates into a modest inventory in the carbonator and calciner reactors (equivalent to about 100 kg/m^2 of crossection of reactor or 1 kPa of ΔP in the risers) despite the relatively intense solid circulation (Gs is represented as a dotted line, with values on the right axis between 2-4 kg/m^{2}s measured indirectly from a heat balance as in [1]). Despite the limited inventory of material in reactor, the carbonator reactor is able to capture around 80% of the CO_2 fed into the reactor. This is facilitated by the high activity of the material in the reactor (low cycle number), which is in turn characteristic of cement plant configurations, where a direct use of the CaO purge from the calcium loop for cement manufacture is feasible.

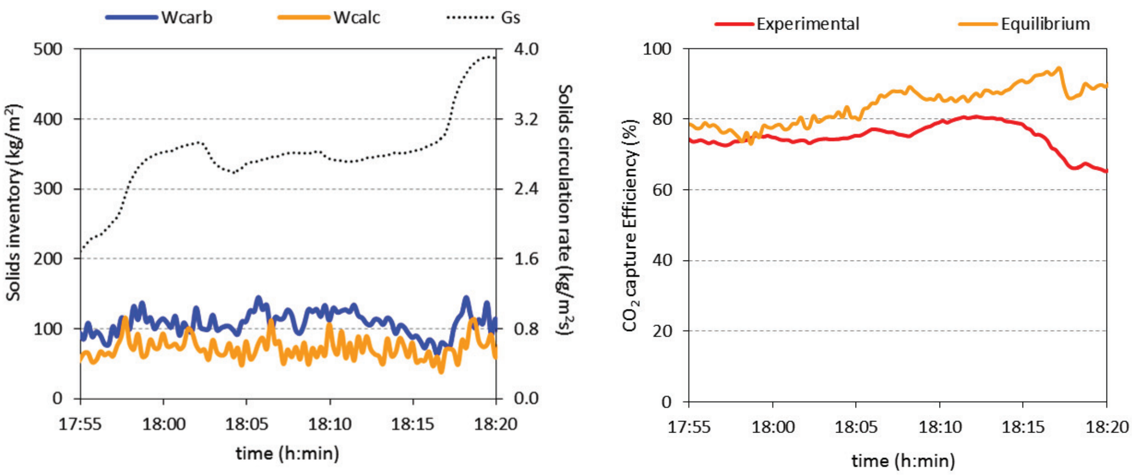

Figure 2. CO_2 capture preliminary results under CEMCAP conditions. a. Solids inventory and solids circulation flowrate b. CO_2 capture efficiency and maximum capture efficiency allowed by the equilibrium. Experimental conditions: T_{carb} = 665 - 730 ºC; inlet u_{carb} = 2.9 m/s, νCO_2 = 18%vol., molar make-up flow = 1.5 mol/m^{2}s and average particle size dp_{50} = 65 μm.

Longer steady state periods of operation (up to 10s of hours duration as described in previous works [16] when using coarser materials) have not been possible under the new configuration with the secondary solid recycle. Despite these practical limitations, a high number of CO_2 capture experiments as in Figure 2 have been completed and confirmed the possibility to achieve high CO_2 capture efficiencies under the new operating conditions (high make up flow of limestone, high CO_2 concentrations). Different gas velocities, CO_2 inlet concentration (10-30%v), reactor temperatures, solid circulation rates and make up flow ratios (or average activity of the material) have been tested. The effect of the presence of steam is also being investigated at present. In general, these results are consistent with the current understanding of CaL in more mature post-combustion capture systems [1-4, 16] but will require a dedicated effort of interpretation with a reactor model, which is ongoing and will be published shortly.

3. Conclusions

Upgrades have been implemented in a 30 kWth CaL test facility at INCAR-CSIC to allow operation at conditions closer to those expected in a CaL system for CO_2 capture in a cement plant. The preliminary experimental results indicate that when using finer limestone solids, higher activity materials (because the lower cycle number) and high CO_2 concentrations in the flue gas, high capture efficiencies can be achievable despite low material inventories in the reactors. Therefore no fundamental barrier should exist to retrofit CaL technology to the cement sector using limestone as CaO precursor and applying design rules developed for CaL in more developed applications of the technology in the power sector.

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References

[1] Arias B., Diego M.E., Abanades J.C., Lorenzo M., Diaz L., Martínez D., Alvarez J., Sánchez-Biezma A., Demonstration of steady state CO2 capture in a 1.7MWth calcium looping pilot, Int. J. Green. Gas. Cont., 2013 18: 237-45.
[2] Alonso M., Diego M.E., Abanades J.C., Perez C., Chamberlain J., Biomass combustion with in situ CO_2 capture by CaO in a 300 kW_{th} circulating fluidized bed test facility, Int. J. Green. Gas. Cont., 2014 29: 142-52.
[3] Ströhle J., Junk M., Kremer J., Galloy A., Epple B., Carbonate looping experiments in a 1 MWth pilot plant and model validation, Fuel, 2014 127: 13-22.
[4] Dieter H., Bidwe A.R., Varela-Duelli G., Charitos A., Hawthorne C., Scheffknecht G., Development of the calcium looping CO2 capture technology from lab to pilot scale at IFK, University of Stuttgart, Fuel, 2014 127: 23-37.
[5] Rodriguez N., Alonso M., Grasa G., Abanades J.C., Process for capturing CO_2 arising from the calcination of the $CaCO_3$ used in cement manufacture, Environ. Sci. Technol., 2008 42: 6980-4.
[6] Blamey J., Anthony E.J., Wang J., Fennell P.S., The calcium looping cycle for large-scale CO2 capture, Prog. Energy Comb. Sci., 2010 36: 260-79.
[7] Naranjo M., Brownlow D.T., Garza A., CO2 capture and sequestration in the cement industry, in: GHGT-10, Energy Procedia, Amsterdam (Netherlands), 2010, pp. 2716-23.
[8] Rodriguez N., Murillo R., Alonso M., Martinez I., Grasa G., Abanades J.C., Analysis of a Process for Capturing the CO2 Resulting from the Precalcination of Limestone in a Cement Plant, Ind. Eng. Chem. Res., 2011 50: 2126-32.
[9] Dean C.C., Dugwell D., Fennell P.S., Investigation into potential synergy between power generation, cement manufacture and CO2 abatement using the calcium looping cycle, Energy Environ. Sci., 2011 4: 2050-3.
[10] Rodriguez N., Murillo R., Abanades J.C., CO2 Capture from Cement Plants Using Oxyfired Precalcination and/or Calcium Looping, Environ. Sci. Technol., 2012 46: 2460-6.
[11] Romano M.C., Spinelli M., Campanari S., Consonni S., Cinti G., Marchi M., Borgarello E., The calcium looping process for low CO2 emission cement and power, in: ICAE2014, Energy Procedia, 2013, pp. 7091-9.
[12] Ozcan D.C., Ahn H., Brandani S., Process integration of a Ca-looping carbon capture process in a cement plant, Int. J. Green. Gas. Cont., 2013 19: 530-40.
[13] Pathi S.K., Lin W., Illerup J.B., Dam-Johansen K., Hjuler K., CO2 capture by cement raw meal, Energy Fuels, 2013 27: 5397-406.
[14] Atsonios K., Grammelis P., Antiohos S.K., Nikolopoulos N., Kakaras E., Integration of calcium looping technology in existing cement plant for CO2 capture: Process modeling and technical considerations, Fuel, 2015 153: 210-23.
[15] M. Spinelli, I. Martínez, E. De Lena, G. Cinti, M. Hornberger, R. Spörl, J.C. Abanades, R. Mathai, C. Fleiger, V. Hoenig, M. Gatti, R. Scaccabarozzi, S. Campanari, S. Consonni, M.C. Romano. Integration of Ca-Looping systems for CO2 capture in cement plants. Energy Procedia (in press), 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland
[16] Rodriguez N., Alonso M., Abanades J.C., Experimental Investigation of a Circulating Fluidized-Bed Reactor to Capture CO2 with CaO, AIChE J., 2011 57: 1356-66.
[17] Telschow S., Frandsen F., Theisen K., Dam-Johansen K., Cement formation-A success story in a black box: High temperature phase formation of portland cement clinker, Ind. Eng. Chem. Res., 2012 51: 10983-1004.